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IN-SERVICE PERFORMANCE AND COSTS OF METHODS TO CONTROL URBAN RAIL SYSTEM NOISE

TEST AND EVALUATION PLAN

Hugh J. Saurenman

Wilson, Ihrig & Associates, Inc.
5605 Ocean View Drive
Oakland CA 94618

Michael C. Holowaty

De Leuw, Cather & Company
121 North Broad Street
Philadelphia PA 19107

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Hugh J. Saurenman Michael C. Holowaty

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Wilson, Ihrig & Assoc., Inc.
5605 Ocean View Drive
Oakland CA 94618

De Leuw, Cather & Company
121 North Broad Street
Philadelphia PA 19107

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16. Abstract

Reported here is the Test and Evaluation Plan of a study to investigate the effectiveness of four techniques for reducing wheel/rail noise in rail rapid-transit systems (resilient wheels, damped wheels, wheel truing, and rail grinding) by implementing a testing program on the SEPTA Market-Frankford Line in Philadelphia. Presented are the methods and equipment which will be used to collect, manage, and reduce the data on both acoustic performance and costs of the four noise-control methods. Included are descriptions of the locations for the noise measurements, the schedule which has been set up for wheel and rail maintenance, and the survey of other transit systems which will be performed to collect information relevant to the application of the noise-control methods.

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Noise, Resilient Wheels, Damped Wheels, Wheel Truing, Wheel Failure

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PREFACE

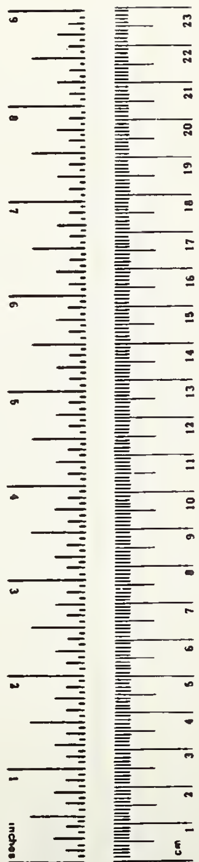
This interim report presents the results of the Test and Evaluation portion of a five task program. The purpose of the program is to develop information on the costs and effectiveness of four methods of controlling wheel/rail noise: resilient wheels, damped wheels, wheel truing and rail grinding. The ultimate goal is to provide information on the noise control methods that individual transit systems can use to evaluate the costs and benefits that would result from application of the methods. The study, sponsored by the Rail Technology Division of the Urban Mass Transportation Administration, Office of Research and Development, is under contract with the Transportation Systems Center, Contract DOT-TSC-1053, for the Urban Rail Supporting Technology Program. This report is the second of the study; the first report covered the experimental design of the study.

The report has been prepared jointly by Wilson, Ihrig & Associates, Inc. (WIA) and De Leuw, Cather & Company (DCCO). The work was technically monitored by Robert Lotz of the Transportation Systems Center. The work was performed principally by Hugh J. Saurenman (WIA) and Michael C. Holowaty (DCCO) with significant contributions by George Paul Wilson, Armin T. Wright and Stanley M. Rosen of Wilson, Ihrig & Associates, Inc.

METRIC CONVERSION FACTORS

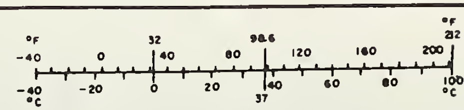
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

This report presents the Test and Evaluation Plan for the study of four methods of controlling wheel/rail noise on rail rapid transit systems: resilient wheels, damped wheels, rail grinding and wheel truing. The Test and Evaluation Plan includes the methods that will be used to collect and manage the data. Described in the report are the locations where measurements will be taken, the manner in which the noise samples will be collected and reduced, the sequential schedule that has been set up for wheel and track maintenance, and the survey of other transit systems that will be performed to collect information relevant to the application of the noise control methods.

The acoustic measurements will be taken at the following track sections, all located on the Market Street section of the SEPTA system:

1) Tangent welded track on ballasted, elevated structure.
2) Tangent jointed track on ballasted, elevated structure.
3) Tangent jointed track in a ballasted, elevated station.
4) Switch frog on ballasted, elevated structure.
5) Short radius curve at grade.
6) Tangent welded track in subway.
7) Tangent jointed track in subway.
8) Tangent welded track in subway station.

In most cases the data will be collected by diverting the revenue service trains around the test track location with single tracking. The test tracks and the methods for data collection have been designed to minimize the time, equipment and personnel required for data collection.

The acoustical measurements to be performed in this study can be conveniently divided into six sequential phases. The measurements that will be taken in each phase are summarized briefly below:

PHASE I: Verify noise measurement and reduction procedure; establish variation between test and control track sections; document noise levels produced by new and worn standard wheels on worn and ground rails; investigate differences between new and trued standard steel wheels.

PHASE II: Evaluate noise characteristics of new resilient and damped wheels on all types of track.

PHASE III: Evaluate progress of wheel and rail wear after approximately six months of wear with profilometer and an abbreviated noise measurement program.

PHASE IV: After an aging period of approximately one year from the end of Phase I, evaluate all combinations of worn wheels and worn rail.

PHASE V: Evaluate noise of worn wheels on newly ground rail.

PHASE VI: Evaluate noise of trued wheels on newly ground rail.

Concurrent with the development and performance of the testing program, cost data relating to each of the noise control methods will be collected, and a survey of existing and soon to be operating transit systems will be conducted to obtain data concerning any experiences they may have had with the four noise control methods being evaluated. The primary source of information on the costs of each of the noise control methods will be observation and analysis of SEPTA operations and costs during the test phase of this study.

1. INTRODUCTION

This interim report is the Test and Evaluation Plan, the second report of a study sponsored by the Rail Technology Division of the Urban Mass Transportation Administration (UMTA) under the technical management of the Transportation Systems Center (TSC). The study is a field evaluation of four methods for controlling wheel/rail noise under conditions that closely approximate normal revenue operations. The testing will be done on the Market-Frankford Line of the Southeastern Pennsylvania Transportation Authority (SEPTA). The previous report covered the experimental design portion of the study.*

The purpose of this report is to present the test and evaluation plan for this study, that is, to detail the methods and equipment that will be used to collect, manage, and reduce the data. The ultimate goal of the study is to provide sufficient information to allow a transit system with given track and car conditions and budgetary constraints to determine the mix of the available methods of control of wheel/rail noise which will result in the greatest overall benefit. Included in the evaluation of greatest benefit is the reduction of noise radiated to adjacent communities and the reduction of patron exposure to noise.

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*Michael C. Holowaty, Hugh J. Saurenman and Stanley M. Rosen, "In-Service Performance and Costs of Methods for Control of Urban Rail System Noise - Experimental Design", DOT Report No. UMTA-MA-06-0025-76-4, Interim Report, May 1976.

The study is designed to provide information on both the long-term and short-term costs and effectiveness of the various noise abatement procedures if implemented on typical urban rail systems in the United States.

Although wheel/rail noise has been shown to be a major source of transit system noise, and some methods have proved to be effective in lowering wheel/rail noise, there is little documented information that can be used to evaluate the reductions that will be realized when a combination of noise abatement methods are used.

The specific noise abatement techniques that will be evaluated in this study are:

1) Resilient Wheels - Wheels with a resilient material between the tire and hub that acts to damp resonant vibration of the wheel and reduce transmission of vibration to the web. Three types of resilient wheels will be included in the study.

2) Damped Wheels - Standard wheels with a vibration damping treatment which acts to reduce wheel vibration.

3) Wheel Truing - Grinding or machining the wheel tire surfaces to a desired degree of smoothness to remove the non-uniformities created during operation.

4) Rail Grinding - Grinding the running rails to eliminate rail roughness created by the passage of trains.

This study is concerned with not only the acoustical evaluation of the four noise abatement methods, but also with the costs of the methods and the combination of the acoustical and cost data to determine optimum combinations of abatement techniques for specific conditions. The study can be logically split into three separate sections as summarized below:

a) Evaluation of acoustical effectiveness of the noise control techniques.

b) Evaluation of the incremental costs associated with implementation of the noise control methods.

c) Combination of the cost and acoustical evaluations into a cost-benefit methodology to allow assessment of the optimum implementation of the noise abatement techniques.

In general, the testing procedure will consist of measuring noise generated by test trains on the Market-Frankford Line of the SEPTA transit system and then comparing the differences associated with the various possible combinations of the four noise control techniques on the different track configurations. An example of the type of information this study will provide is whether certain wheels afford a significant reduction in noise on one particular type of track, but are ineffective on others.

A cost analysis will be performed to investigate the relationship between noise reduction and costs. Since both the immediate and the long-term costs and benefits will be evaluated along with the initial capital cost attendant with each combination, the study will be of two years duration.

To optimize the benefits from the proposed noise control methods, other factors, such as ease of implementation, longevity, and required maintenance, will be taken into consideration.

The previous report of this study, the Experimental Design Interim Report, presented:

1) The questions the study is designed to answer.

2) The parameters that will be used to evaluate the noise control methods.

3) An outline of the general methods that will be used to analyze the evaluation parameters.

This report establishes the details of the methods that will be used to collect and manage the data. The primary purpose of this report is to describe what measurements will be taken, where the measurements will be taken, and the manner in which the noise samples will be collected and reduced. This report does not indicate the methods that will be used to analyze and interpret the data once it has been collected, as they have been covered in some detail in the Experimental Design Report.

The methods to be used and the scheduling for collection of the data on wheel/rail noise are the primary topics covered in this report. The parallel investigative program that will be carried out to gather information on the four noise control methods from existing transit systems will primarily consist of telephone and in person interviews.

The remainder of this report has been divided into three sections. Section 2 is a general discussion of the program

schedule, and Section 3 covers the specifics of the acoustic data collection including the location of the test tracks, the instrumentation for the acoustic data samples, the instrumentation and methodology for the data reduction, the management and cataloging of the acoustic data along with the contingency plans in case of some equipment failures, and a summary of the system restorations that will be necessary following the test series. Section 4 briefly summarizes the collection of the data for the cost parameters and the qualitative parameters.

2. PROGRAM SCHEDULE

To collect data that can be used by transit systems to determine the best method of controlling wheel/rail noise, two parallel efforts will be carried on simultaneously. First, an experimental program in which wheel/rail noise will be measured for most combinations of the program parameters, and second, an investigative program in which data and information concerning the knowledge and experiences of existing transit systems will be gathered and analyzed. These parallel efforts will be coordinated throughout the program to assure that appropriate data are being developed.

The acoustical measurement program for wheel/rail noise has been divided into six phases. The accompanying functions of the acoustical program, such as wheel truing and grinding, collection of data from other transit systems, and wheel and track profile measurements, are not explicitly included in the testing phases. The sequence and schedule of the testing events is important since time, expressed in rate of surface wear, is one of the primary evaluation parameters. To evaluate the rate of wear, the rail roughness will be measured during the one year deterioration period.

Figure 2-1 is a simplified flow diagram of the entire study program including the acoustical measurements and analysis, the collection of the cost information and development of the cost-benefit analysis. The flow diagram shows the major segments of the test program. The study can be conveniently divided into two segments; one preceding and one following the approximately one year period during which wheels and rails will be allowed to wear normally without

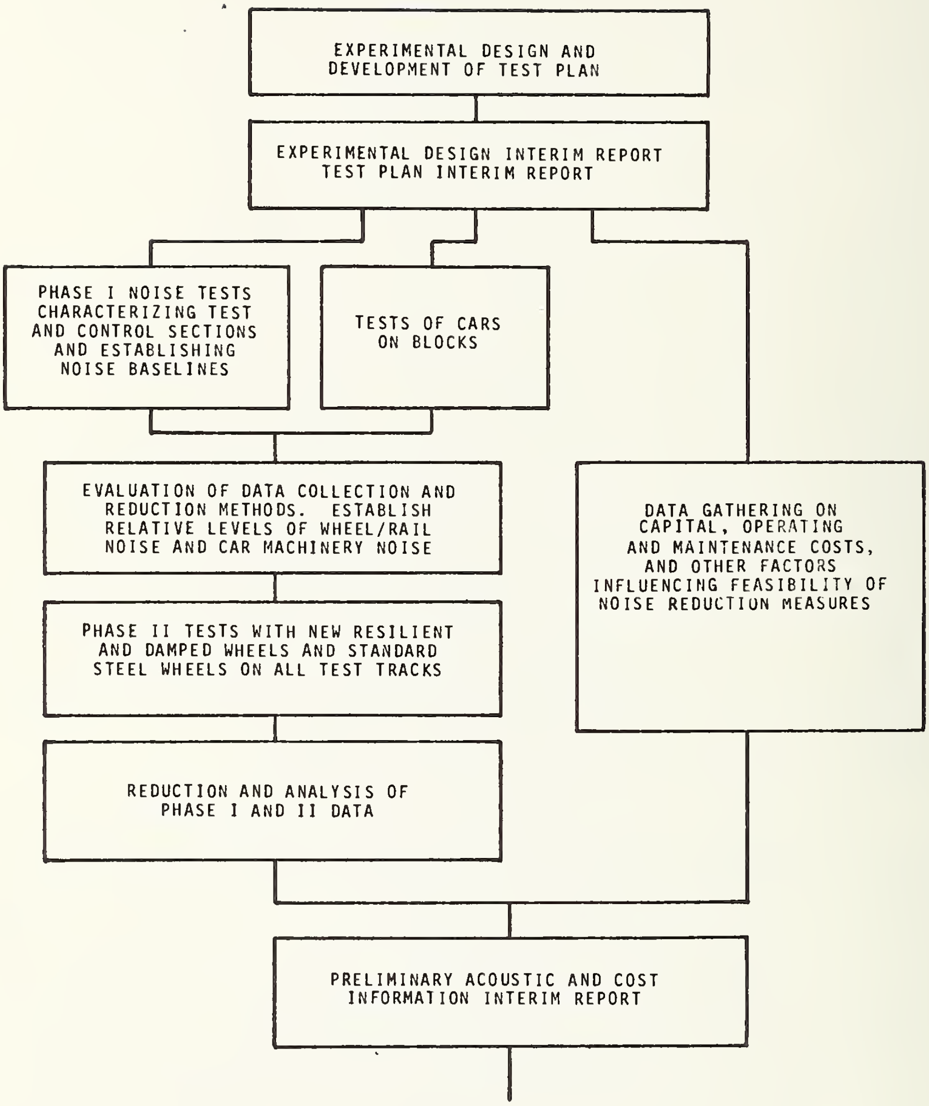


Figure 2-1 Flow Diagram of Study Program

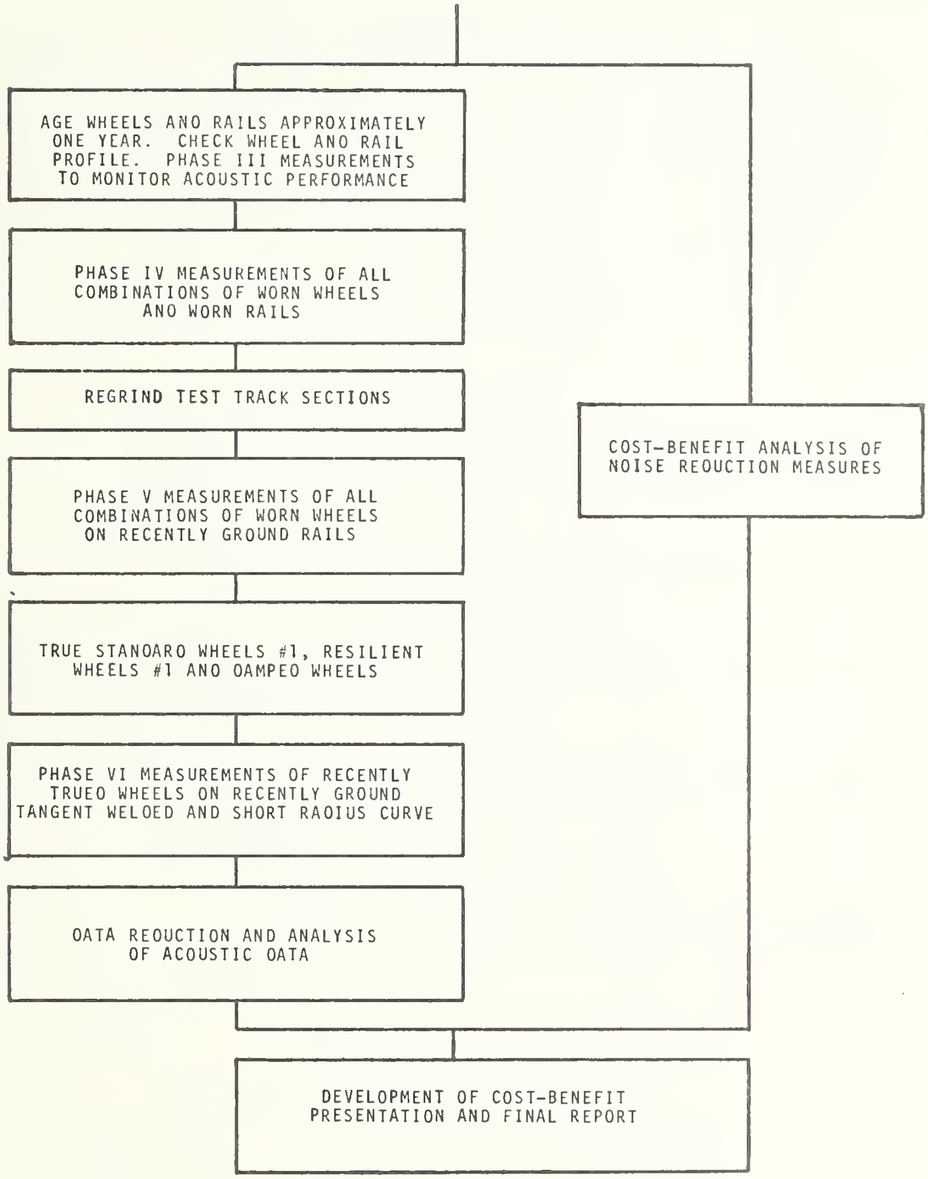


Figure 2-1 Flow Diagram of Study Program (cont'd.)

truing or grinding. An interim report will present the results of the first segment of the program. The final report will present the results of the acoustical and cost analysis along with the cost-benefit analysis.

A summary of the sequence of the testing events with the approximate time period between the events in each of the six test phases is outlined in Table 2-1. All of the tests that will be performed are tabulated in Table 2-2. A full description of each phase of the test are described in Sections 2-1 to 2-6. To simplify the tables and the description of test phases, the following abbreviations and acronyms have been used.

TW	-	tangent welded test section (elevated structure)
TJ	-	tangent jointed test sections (elevated structure)
SUB	-	all subway test tracks including: tangent welded, tangent jointed, and station welded
TURN	-	short radius turn at the 69th Street Turnaround
FROG	-	switch frog (elevated structure)
ELESTN	-	elevated station
G	-	ground rail
UG	-	unground rail
RG	-	reground rail
A	-	aligned joints
UA	-	unaligned joints
C	-	control track section. The control track sections will not be ground or aligned during the length of the stay.

TABLE 2-1. SEQUENTIAL SCHEDULE FROM START OF TESTING

WEEK	PHASE AND TIME PERIOD
1-2	Phase IA 5 Test Days 2 trains and cars on jacks
3-5	Grind TW, TURN and align TJ section B
6	Phase IB 2 Test Days 2 trains
7	True new standard wheels
8	Phase IC 2 Test Days 2 trains, single tracking
9-10	Check Phase I measurements, etc. Determine if there are significant differences between trued and untrued wheels
11	Phase IIA 4 Test Days 4 trains
12-14	Grind all SUB and TJ experimental sections
15	Phase IIB 4 Test Days 6 trains
16-33	Wear period
34-35	Phase III 2 Test Days 6 trains
36-59	Wear period
60-61	Phase IV 4 Test Days 6 trains
62-64	Regrind all test tracks and check joint alignment
65	Phase V 4 Test Days 6 trains
66	True three sets of wheels
67	Phase VI 2 Test Days 3 trains

TABLE 2-2. SUMMARY OF ACOUSTIC MEASUREMENTS

PHASE	TEST TRACK CONFIGURATIONS	SPEEDS	MEASUREMENT LOCATIONS		WHEEL TYPE					
			Interior	Exterior	Std. 1	Std. 2	Resil. 1	Resil. 2	Resil. 3	Damped
PRELIMINARY	CARS-ON-BLOCKS	2	X[1]	X	X	X				
IA	TW [UG;C]	3	X	X	X	X				
	TJ [UG & UA;C]	3	X	X	X	X				
	TURN [UG;C]	N[2]	X	X	X	X				
IB [Grind TW, align TJ joints]	TW [G;C]	3	X	X	X	X				
	TJ [UG,A;C]	3	X	X	X	X				
	SUB [UG]	3	X	X[3]	X	X				
	TURN [G;C]	N	X	X	X	X				
IC [True std. wheel set 2]	TW [G;C]	3	X	X	X[4]	X				
	TURN [G;C]	N	X	X	X	X				
IIA [Mount and measure damped and all resil- ient wheels]	TW [G;C]	3	X	X			X	X	X	X
	TJ [UG & A;C]	3	X	X			X	X	X	X
	SUB [UG]	3	X	X			X	X	X	X
	TURN [G;C]	N	X	X			X	X	X	X
IIB [Grind TJ & SUB Test Tracks]	TJ [UA & G; A & G;C]	3	X	X	X	X	X	X	X	X
	SUB [G]	3	X	X	X	X	X	X	X	X
	FROG	3	X	X	X	X	X	X	X	X
	EL STN	N		X	X	X	X	X	X	X

[1]An X in the column indicates that the wheel type or measurement location will be included in the test series.

[2]N indicates the testing will be performed at "normal" speed only.

[3]In subway tests, exterior refers to measurements made inside a station.

[4]Solo single cars will be measured in this test to document the difference in passby levels between 1- and 2-car trains.

TABLE 2-2. SUMMARY OF ACOUSTIC MEASUREMENTS (cont'd.)

PHASE	TEST TRACK CONFIGURATIONS	SPEEDS	MEASUREMENT LOCATIONS Interior	Exterior	WHEEL TYPE Std. 1	Std. 2	Resil. 1	Resil. 2	Resil. 3	Damped
III [Interim tests following six month wear period]	TW [G,C][5]	2	X		X	X	X	X	X	X
	TJ [UG & A;G & A;C][5]	2	X		X	X	X	X	X	X
	SUB [G]	2	X		X	X	X	X	X	X
	TURN[5]	N	X		X	X	X	X	X	X
IV [End of one year wear period]	TW [G,C]	3	X	X	X	X	X	X	X	X
	TJ [UA & G; A & G;C]	3	X	X	X	X	X	X	X	X
	SUB [G]	3	X	X	X	X	X	X	X	X
	TURN	N	X	X	X	X	X	X	X	X
V [Regrind and check joints on all experimental track sections]	TW [RG;C]	3	X	X	X	X	X	X	X	X
	TJ [UA & RG; A & RG;C]	3	X	X	X	X	X	X	X	X
	SUB [RG]	3	X	X	X	X	X	X	X	X
	TURN [RG;C]	N	X	X	X	X	X	X	X	X
VI [True three sets of wheels]	TW [RG;C]	3	X	X		X	X			X
	TURN [RG;C]	N	X	X		X	X			X

[5]Wheel vibration on at least two wheel sets will be monitored on these tests.

2.1 PHASE I

The Phase I tests will verify the data acquisition and reduction methodology, establish noise baseline for standard conditions, document noise characteristics of control cars and control tracks, and document noise levels produced by new, worn, and trued standard wheels on worn and ground rails. This phase is split into three separate sets of tests.

In test Phase IA the standard wheel sets no. 1 (worn) and no. 2 (new) will be tested on the experimental and control sections of the TW, TJ and TURN test tracks. Both wayside and car interior data will be collected in Phase IA. In addition, the Phase IA tests will be used to verify the applicability and efficiency of the methods that have been set up to both collect the acoustic data and reduce the data. Section 3.3, FIELD DATA ACQUISITION SYSTEMS, describes the equipment systems that are planned for collection of the data in the field and reduction of data in the laboratory. Time has been allocated in the study for review and verification of both the data acquisition and reduction methodology during Phase IA.

Following the Phase IA tests, the experimental sections of the TURN and TW test tracks will be ground smooth. In addition, the joints will be aligned for the TJ experimental section B. The passby tests of the Phase IB will then be conducted.

The Phase IB tests will include testing both sets of standard wheels on the TW, TURN and SUB test tracks. Following Phase IB, the new standard wheels (set no. 2) will be trued. The Phase IC tests will include the trued standard wheels (set no. 1) and single cars of the worn standard

wheels (set no. 2). The single car tests will be performed to give some basis for relating noise from a 1-car train to a 2-car train. This test is important in case of failure of one car of a 2-car train forcing its removal from testing. Data collected using the remaining car could still be used.

The purpose of the tests in Phase IC with the trued standard wheels will be to establish if there is any significant difference existing between the noise radiating characteristics of the new wheels and the trued wheels.

In addition to the tests that will be performed on the test trains, measurements will be taken in Phase I of normal revenue trains on the TW, TJ and TURN test tracks. Also, on the TJ and TW test tracks, extra wayside measurements will be taken at distances farther than 25 feet from the track. The extra wayside measurements will aid in relating the measurements taken 25 feet from the track to distances farther from the track. Along much of the elevated system, the nearest buildings are 50 to 100 feet from the tracks.

2.2 PHASE II

Phase II will evaluate and compare noise characteristics of new resilient and damped wheels with trued and worn standard wheels on all types of track. In Phase IIA, the resilient and damped wheels will be tested on the TW, TJ, TURN and SUB test tracks.

Following Phase IIA, experimental section B of the TJ test track and the entire subway test track will be ground smooth. In Phase IIB, measurements will be made with all six 2-car sets of wheels on the TJ, SUB and FROG test tracks. In addition, standard wheel set no. 2 will be measured on the elevated station platform. Note that Phase IIB is the only time that measurements will be taken at the elevated station test track.

2.3 PHASE III

Following Phase II, the wheels and rails will be allowed to age and wear under normal revenue service conditions for one year. During this period, the wheel and rail roughness will be measured to establish the rates of wear and surface deterioration. Also, after approximately six months of normal revenue service, an abbreviated set of acoustic measurements, Phase III, will be taken.

The purpose of the Phase III tests is to monitor the acoustic performance after a relatively short aging period, i.e., six months, and indicate the manner with which wheel and rail aging influences noise radiation. Further, the abbreviated tests will provide substitution data in case of later contingencies.

The measurements will be taken with all six sets of wheels on the TW, TJ and TURN test tracks. Instead of the normal six passbys of each train on each test track, this series of tests will include only four passbys of each train on each test track.

The Phase III tests will include only interior measurements, hence the measurements will be taken in a different manner than for the other tests. Three of the 2-car sets will be combined into one 6-car train with an instrumentation setup for measuring interior noise in one car of each 2-car train. The 6-car train runs will be intermixed with the normal revenue service trains. Only four complete round trip circuits with each 6-car train will be required to obtain the necessary data.

During Phase III, measurements will also be taken of the wheel vibration for at least two types of wheels. Tentatively the vibration measurements are scheduled for the new

standard wheels and the Acousta Flex resilient wheels. If possible, the wheel vibration measurements will be expanded to include more than two types of wheels.

The results of the wheel vibration measurement will supplement the acoustic data and allow deeper investigation of the noise producing mechanisms.

2.4 PHASE IV

After an approximately one year aging period from the end of the Phase II tests, all the combinations of worn wheels and worn rail will be evaluated in the Phase IV tests. Measurements will also be made of revenue service trains on the TW test track. The TW, TJ, TURN and SUB test tracks will all be included in this series of tests.

The Phase IV tests will examine wheels and rail that have both aged for one year without surface maintenance. Comparison of this data with the data from new wheels and smooth rail will indicate the influence of aging on noise radiation.

2.5 PHASE V

Following the Phase IV tests, all the experimental rail sections will be ground smooth. Phase V will evaluate the noise radiated by the worn wheels with all the experimental track sections of the TW, TJ, TURN and SUB test tracks reground. The data from Phase V will provide information on the degree to which rail grinding without wheel truing will reduce radiated noise levels.

2.6 PHASE VI

For the final tests of Phase VI, the Penn Bochum, vibration damped, and standard no. 2 wheel sets will be trued. Measurements of these three wheel sets will then be made on the TW and TURN test tracks only. The purpose of this series of measurements will be to determine if the measurement on newly ground rail with new wheels made in Phase I and Phase II can be repeated with wheel truing and rail grinding. The results will also help in the evaluation of variations in noise level caused by uncontrolled factors, such as weather.

3. ACOUSTICAL DATA COLLECTION

This section presents the schedule of test events and the data acquisition and reduction methods that will be used to collect data on wheel/rail noise. The experimental program of measurements of wheel/rail noise will involve different types of track construction along with most combinations of worn and ground rail and factory new, worn and trued wheels of various designs.

Two possible methods may be used to take the measurements. The first method is to isolate specific test track sections by using single tracking of the normal revenue service trains. The test trains are then operated under controlled conditions over the isolated test track sections. The second method is to intermix the test trains with the normal revenue service trains. Each time a test train makes a circuit of the system, as many test tracks as possible would be instrumented for measurements. Using single tracking simplifies the data collection procedures and reduces the possibilities for losing data; however, using the test trains mixed with revenue service trains minimizes the total number of train operations. At this time single tracking tests are planned for all the measurements except for Phase III. Phase III is an abbreviated set of measurements where only car interior data will be collected; the measurements can be taken during normal revenue service.

3.1 TEST TRACK SECTIONS

The test track sections have been marked out on the Market Street elevated and subway sections of the Market-Frankford rapid transit line. Figure 3-1 illustrates the

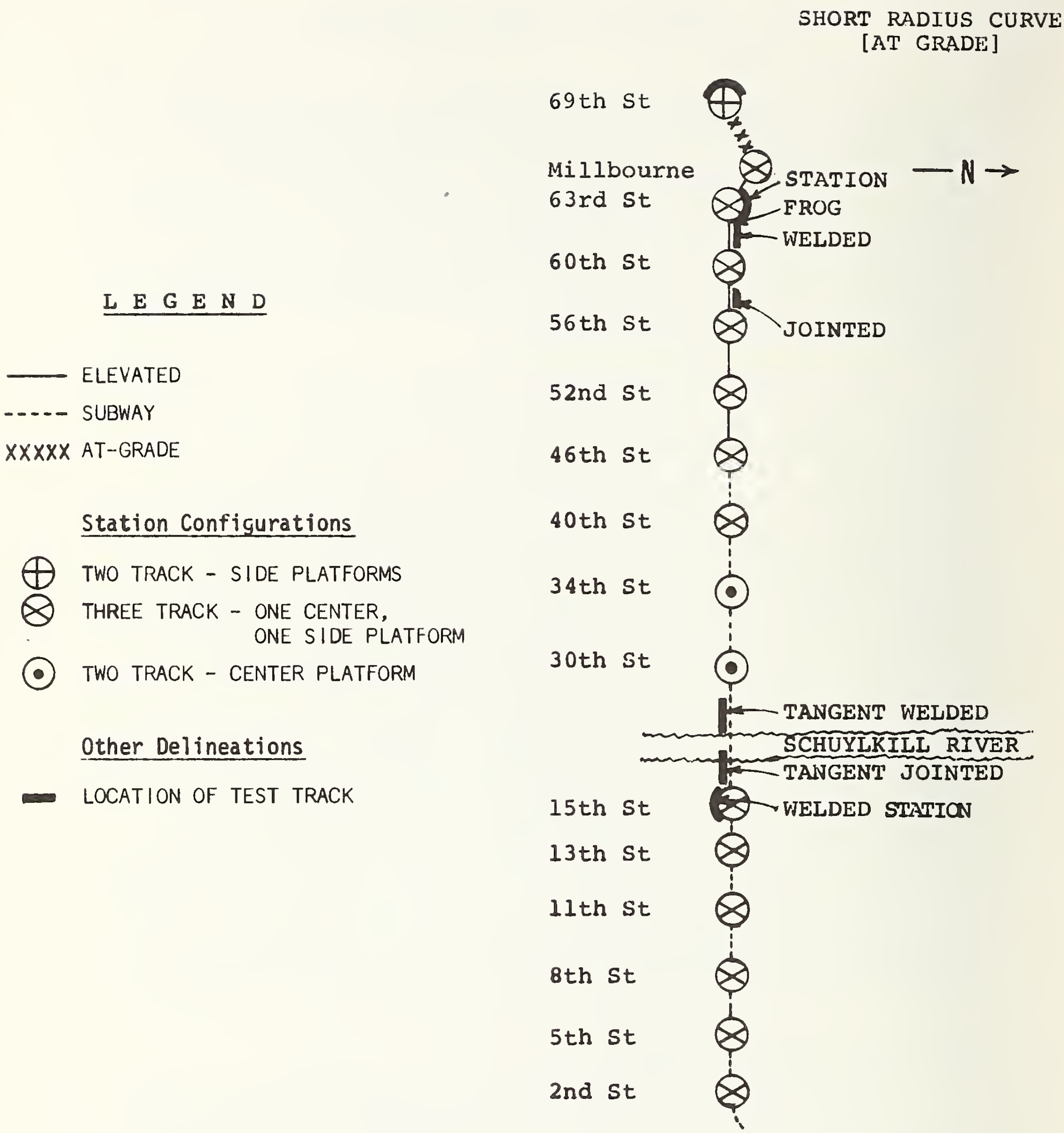


Figure 3-1 Schematic of Market Street Subway Elevated System

general locations for each of the test track sections. The test tracks have been located to minimize the total number of single tracking operations that will be necessary. Wherever possible, adjacent track sections have been used with the result that only three separate test track sections allow measurement of eight different combinations of track and track structure.

Figure 3-2 illustrates the test track on the ballasted elevated structure. The track is the westbound track between the 56th Street and 63rd Street Stations. Included within the test track are a test section and control section of tangent welded track, two test sections and a control section of tangent jointed track, a frog, and an elevated station with jointed track (63rd Street Station). Photographs of each of the test areas on elevated structure are shown in Figure 3-3. The elevated structure is approximately 30 feet wide between the handrails of the walkways. The buildings adjacent to the elevated structure are approximately the same height or slightly taller than the structure and are separated from the edge of the elevated structure by approximately 30 to 50 feet. Hence, there is very little likelihood that the acoustical measurements will be influenced by any nearby buildings or other large reflecting surfaces.

The subway test track section is illustrated in Figure 3-4. The test sections included in the subway are tangent jointed track just east of the 19th Street Subway-Surface Station, tangent welded track east of the 22nd Street Subway-Surface Station, and tangent welded track extending through the eastbound side of the 15th Street Station. Noise measurements will be taken on the eastbound platform of the 15th Street Station.

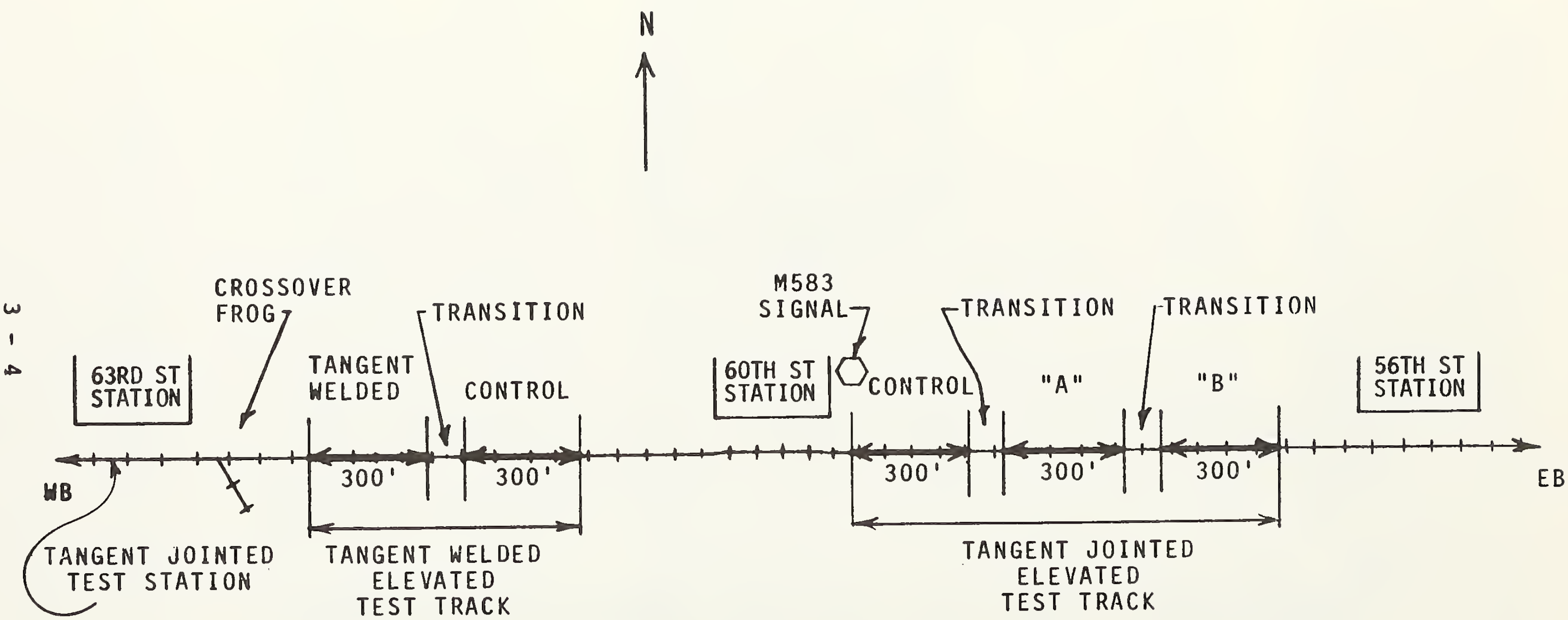
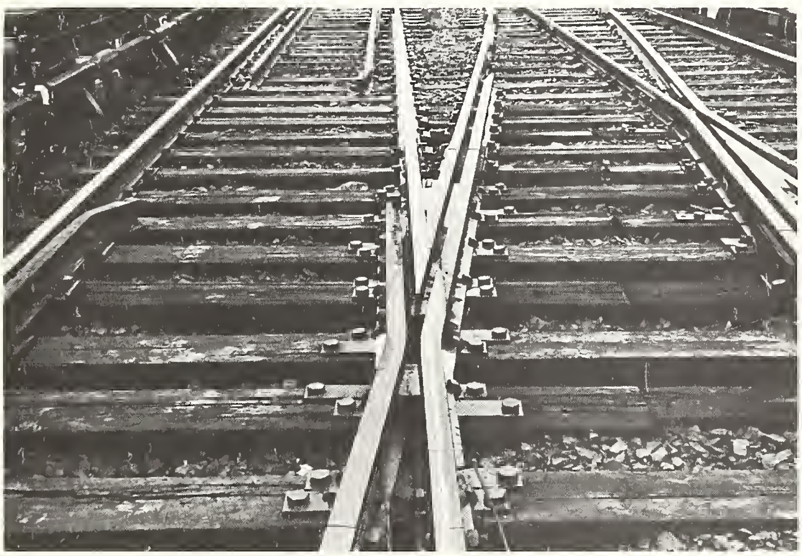


Figure 3-2 Elevated Structure Test Track

TYPICAL VIEW OF BALLASTED DECK
OF ELEVATED STRUCTURE



CROSSOVER FROG ON ELEVATED STRUCTURE

Figure 3-3 Photographs of the Market Street Elevated Structure

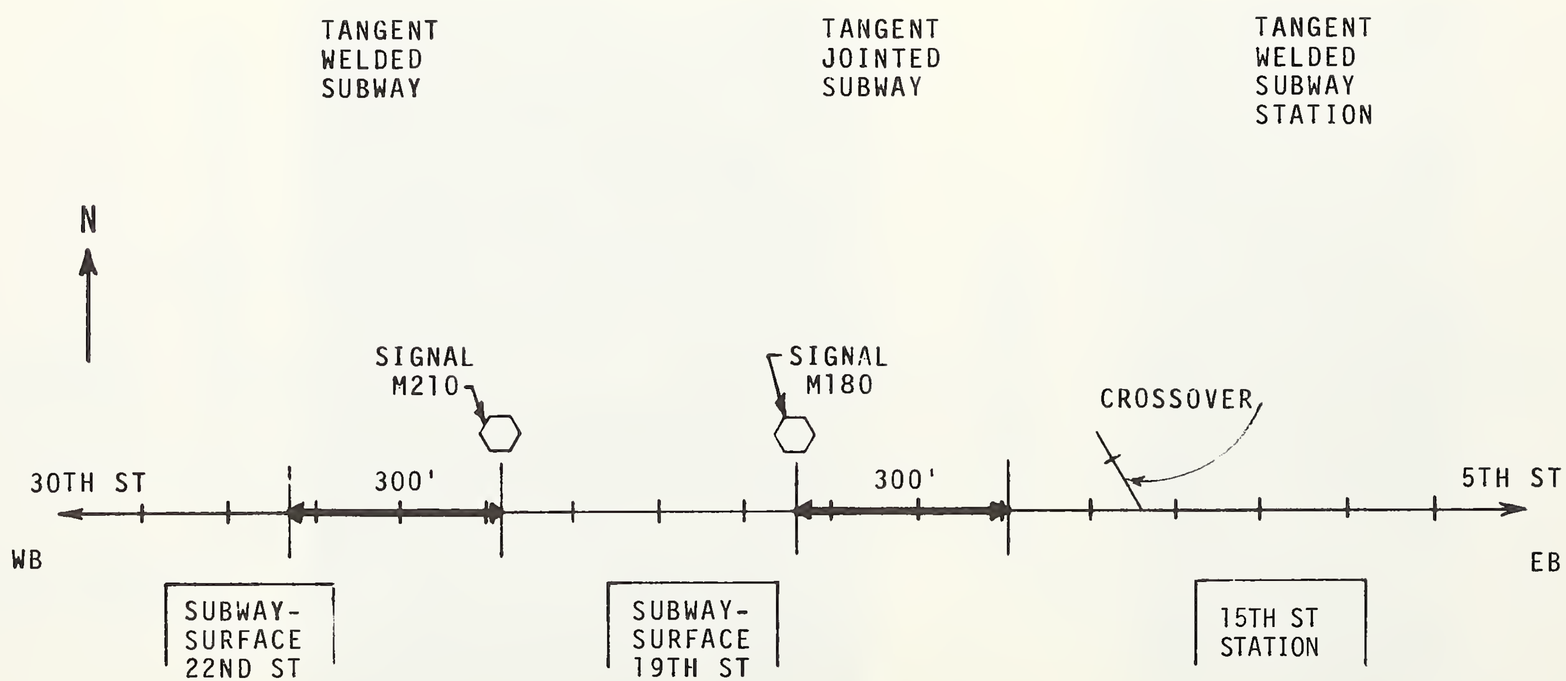


Figure 3-4 Subway Test Track

Almost all of the track in the subway section of the Market Street Line is tangent jointed with only short sections of welded rail; there are very few welded sections available for testing. The section of welded track that has been chosen is the only appropriate section for the tests. However, the entire welded section chosen is less than 300 feet long and there is one joint in the middle of the test section.

Simultaneous with measurement of car interior noise on the tangent welded subway test track, rail vibration, invert vibration, and ground vibration measurements will be taken. These measurements will be analyzed by personnel of the Port Authority of New York and New Jersey. The basement of 2116 Market Street, adjacent to the subway structure, will be used for the ground vibration measurements since there is no appropriate location at the ground surface in the vicinity of the test track.

The only short radius subway curve appropriate for this study is the curve just east of the 2nd Street Station. There are no other subway curves where significant wheel squeal has been observed. However, the new construction on the Frankford section of the transit system precludes use of this curve in the study. Hence, it is necessary to remove the short radius subway curve from the study.

As shown in Figure 3-5, the turnaround track at the 69th Street Station has been chosen as the short radius curve (at grade) test track. The curve has approximately an 140 foot radius. Normal revenue service trains using the turnaround generate a considerable amount of wheel squeal on this track section even though the rails are greased on a regular schedule. Prior to each set of tests on the turnaround, it will be requested that the rails not be greased

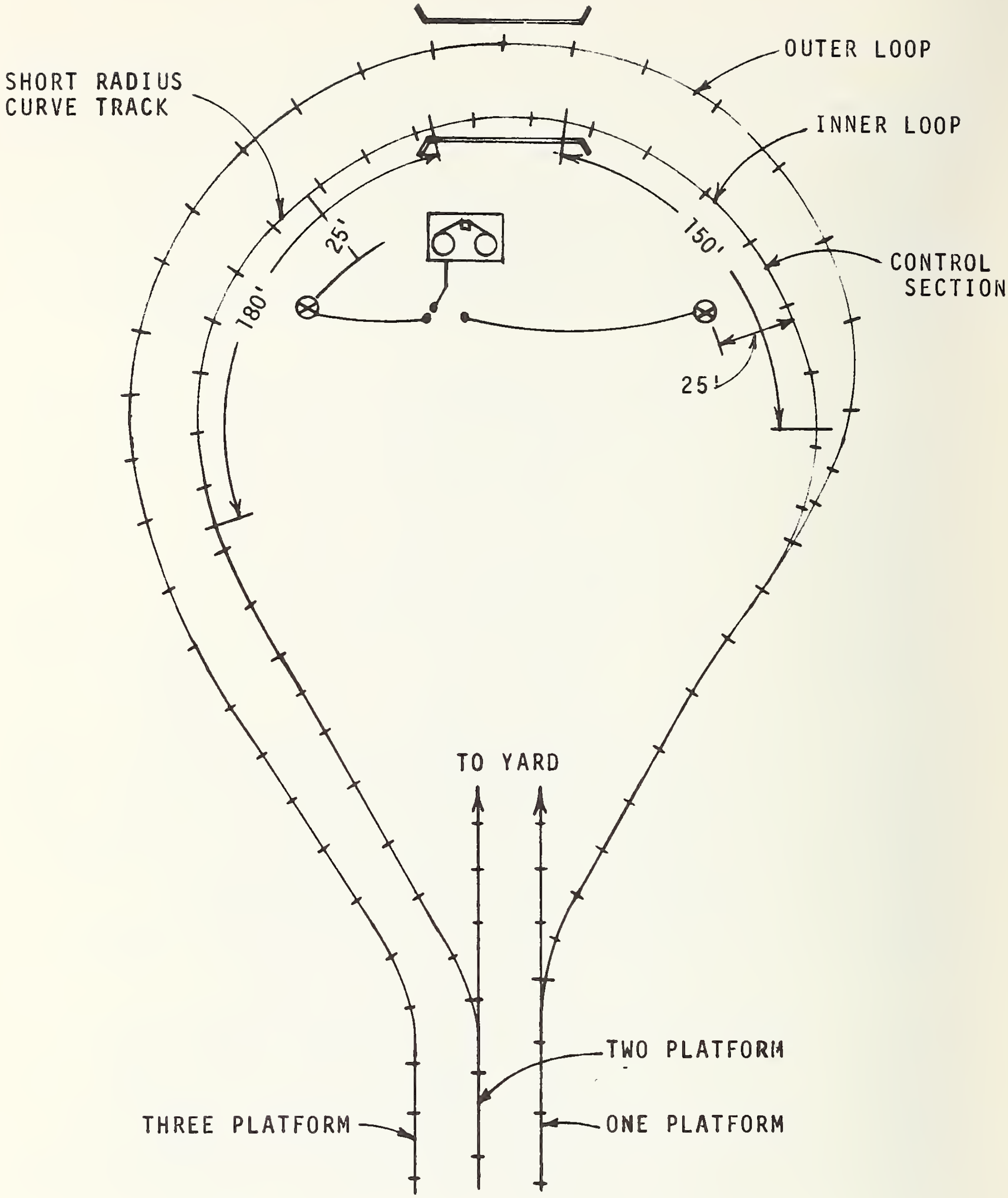


Figure 3-5 Sketch of Short Radius Curve (At Grade) Test Track - Inside Turnaround Track at 69th Street Station

for one week. Since it has a smaller radius and more uniform curvature, the inside track has been chosen for the test track.

Figure 3-6 shows two photographs of the turnaround track section. The turnaround track is a relatively tight turn with the wayside reasonably clear of any obstructions that would influence the sound radiated.

3.2 WHEELS

A total of six complete 2-car sets of wheels will be used in the program. Each set of wheels will be mounted on recently overhauled 2-car trains. The wheels to be used are:

Standard No. 1 - To investigate the effects of a wear period longer than one year, a set of worn standard steel wheels will be included. These will be chosen from wheels that have already been used on the SEPTA system for some time.

Standard No. 2 - These wheels will be new, solid steel wheels of the standard type used on the SEPTA system.

Resilient No. 1 - These wheels will be Penn Cushion (Bochum) wheels supplied by the Penn Machine Company. The wheel has a rubber spring vibration isolator between the wheel hub and the tire as shown in Figure 3-7.

Resilient No. 2 - Resilient No. 2 will be Acousta Flex wheels made by the Standard Steel Company. As shown in Figure 3-8 the Acousta Flex wheel is similar in concept, though of different

TRANSITION BETWEEN TEST SECTION
AND CONTROL SECTION OCCURS AT BRIDGE.
THE CONTROL SECTION IS IN THE FOREGROUND.

THE TEST SECTION IS IN THE FOREGROUND

Figure 3-6 Photographs of 69th Street Turnaround

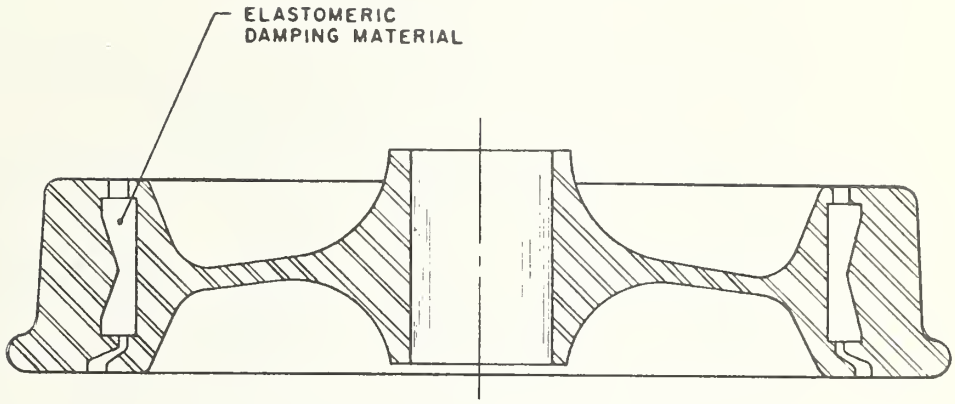


Figure 3-7 Penn Cushion (Bochum) Resilient Wheel

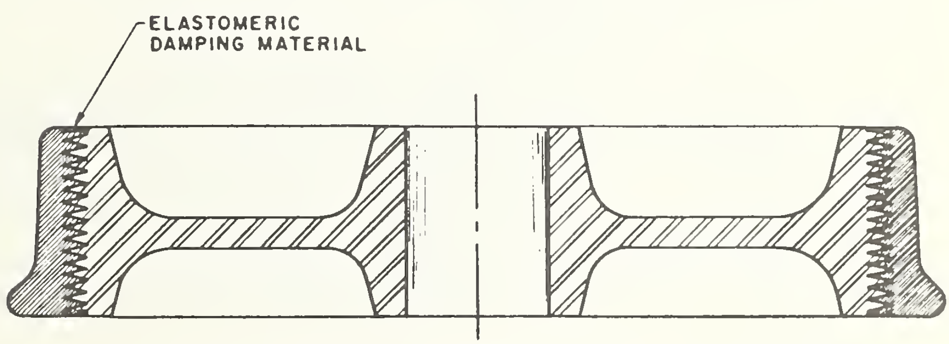


Figure 3-8 Acousta Flex Resilient Wheel

construction, to the Bochum wheel. The center is aluminum instead of forged steel. Isolation is provided by a thin layer of resilient material injected between large mating threads at the interface of the aluminum center and steel tires.

Resilient No. 3 - Resilient No. 3 will be the SAB resilient wheel sketched in Figure 3-9. The wheel is similar in design to the PCC streetcar super-resilient wheel, but of heavier construction.

Vibration Damped - The damped wheel uses standard steel wheels with vibration dampers installed. Figure 3-10 illustrates schematically the arrangement of the dampers on the wheel rim.

The initial set of tests, Phase I, will be performed with the two sets of standard steel wheels. Both the difference between the new and worn wheels and the difference between worn and smooth track will be investigated. Following Phase I, generally all six sets of wheels will be included in the tests.

In the one year deterioration period, the wheel profile and roughness will be checked several times. These checks will give data on the wear rates and the optimum maintenance schedule.

The roundness and wobble of the wheels will be measured during the initial study phase and following the one year wear period.

To document the distances traveled by each test train during the one year deterioration period, a hubodometer will be installed on each test car.

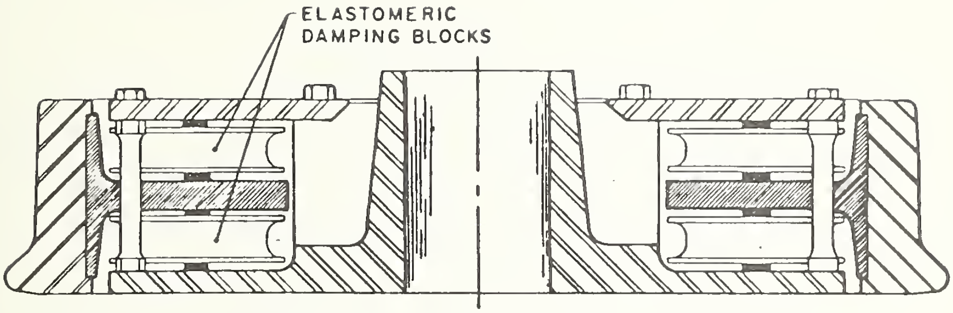


Figure 3-9 SAB Resilient Wheel

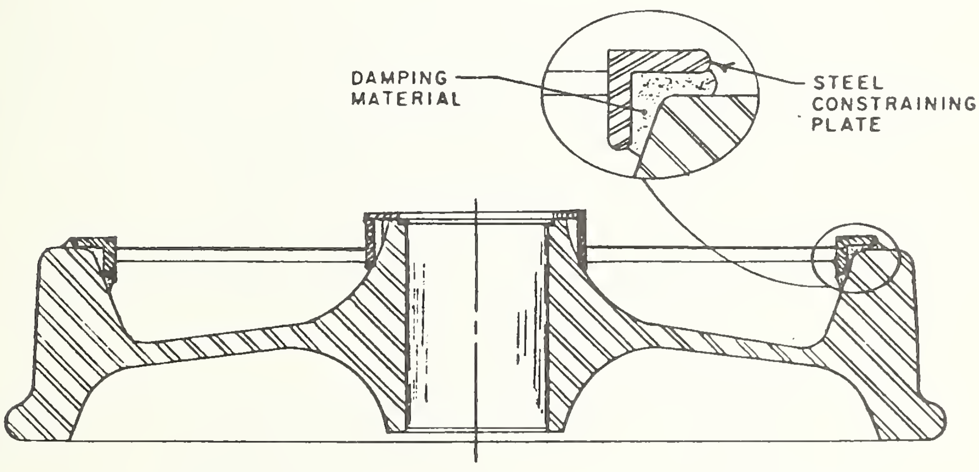


Figure 3-10 Damped Standard Wheel

Following the wear period, three wheel sets will be trued on the SEPTA milling machine wheel truer. When the wheels arrive from the factory, they will be smooth and true, having been lathe turned. To investigate the difference in noise radiating characteristics between new and trued wheels, in Phase I standard wheel set no. 2 will be tested in both the new and trued condition.

3.3 FIELD DATA ACQUISITION SYSTEMS

All acoustical testing, where possible, will be in compliance with draft UITP (International Union of Public Transport), APTA (American Public Transit Association), ISO (International Organization for Standardization) or ASA (Acoustical Society of America) standards for measurement conditions and equipment. UITP standards call for testing at speeds of 40, 60 and 80 kilometers per hour and interior measurements at points 1.2 meters above the floor along the car centerline over one truck pivot and at the center of the car. Wayside measurement points have been determined after a thorough examination of potential test sites. On the elevated structure, the microphones will be located 25 feet from the track centerline which is approximately 5 feet beyond the walkway railing on the opposite side of the elevated structure from the test track. The standard wayside measurement positions recommended in the UITP draft standard (7.5 meters from track centerline and 1.5 meters above top-of-rail) will be employed.

The acoustical measurement apparatus will be calibrated regularly in compliance with applicable standards, and will be checked at the beginning and end of each measurement session by means of a pistonphone or acoustical calibrator.

Only laboratory grade, Bruel & Kjaer condenser microphones and Nagra precision magnetic recorders or equivalent will be employed for sound and vibration data gathering in the field. Vibration measurements will employ piezoelectric accelerometers. The sound and vibration data will be recorded on analog magnetic tape for subsequent analysis and permanent storage in the WIA laboratory.

Figure 3-11 is a block diagram illustrating in more detail the field data acquisition systems that will be used at the elevated structure wayside locations. An operator will be positioned with each tape recorder to turn on the tape recorder as the test train approaches a test track. The operators will use the announce microphone to verbally note the run number, location, etc., for each sample. In addition, the tape recorder operator will have a switching box to select the appropriate microphone which will allow one operator and tape recorder to collect data from several microphone positions.

Figure 3-12 is a block diagram of the equipment setup that will be used to collect data on rail and structure vibration of the elevated structure. The collection and reduction of the vibration data will be performed by personnel from the Port Authority of New York and New Jersey. The tentative schedule for vibration measurements includes measurement during test Phase I and II on tangent welded track on the elevated structure and in the subway.

The equipment setup to be used inside the test trains is shown in the block diagram of Figure 3-13. Since the trains are not equipped with speedometers, the speeds will be measured and recorded using a portable radar speedometer. Illuminated remote readouts from the speedometer will be located in each operator's cabin and at the tape recorder.

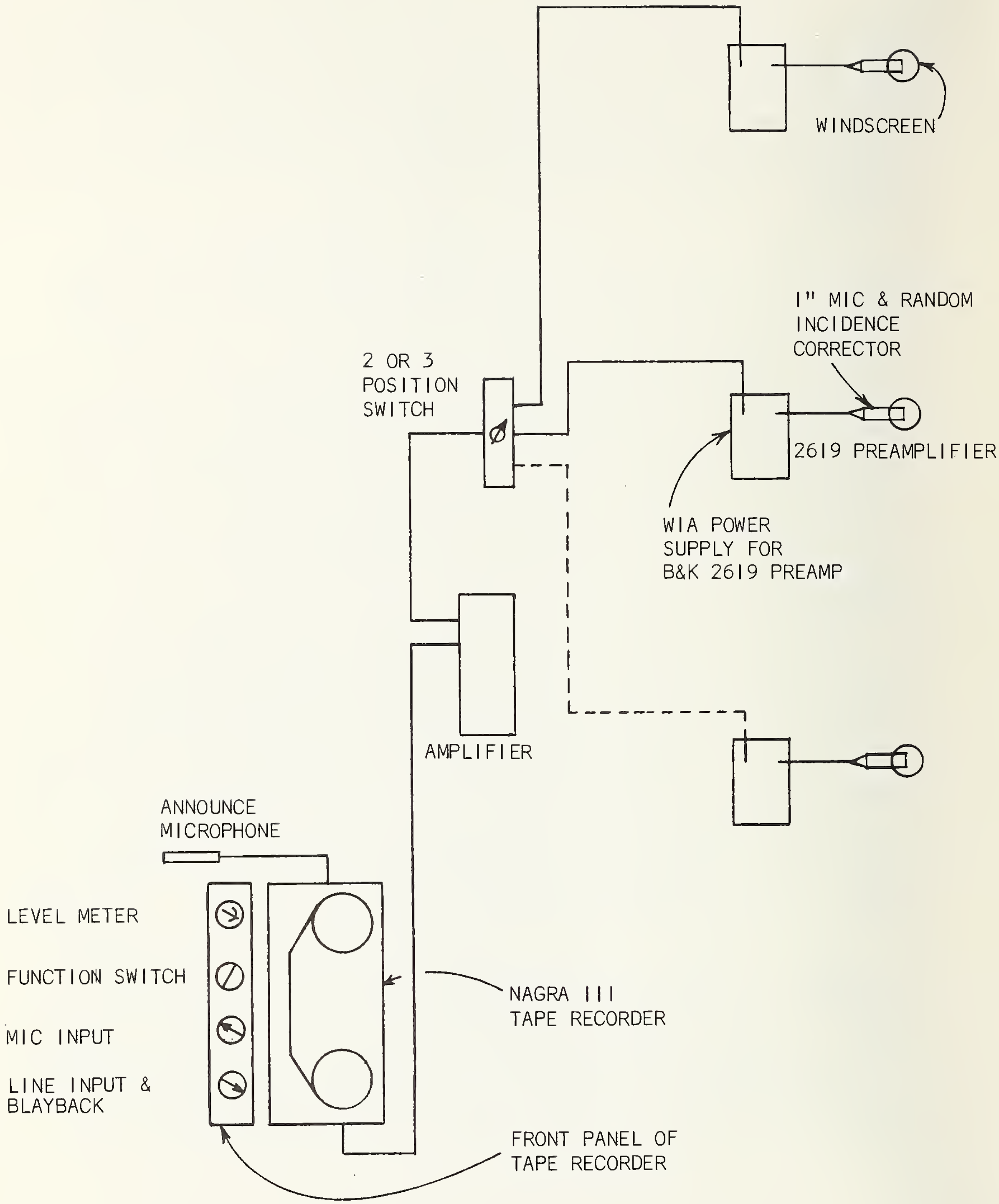


Figure 3-11   Block Diagram of Equipment for Wayside Acoustic Measurements of Elevated Structure and Turnaround

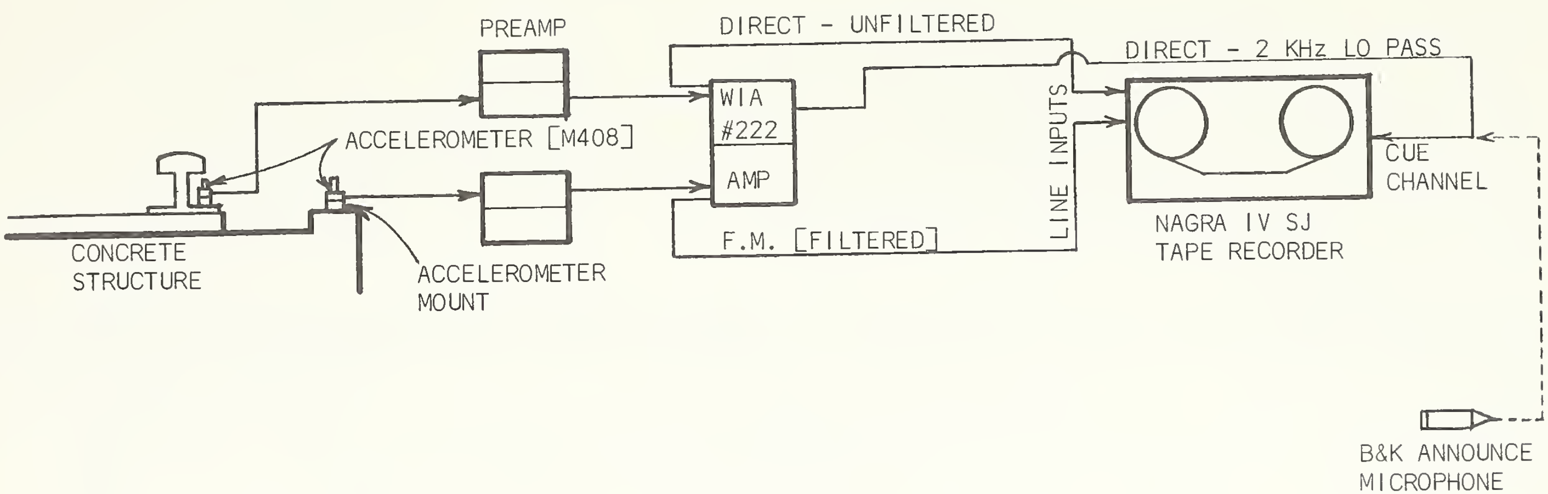
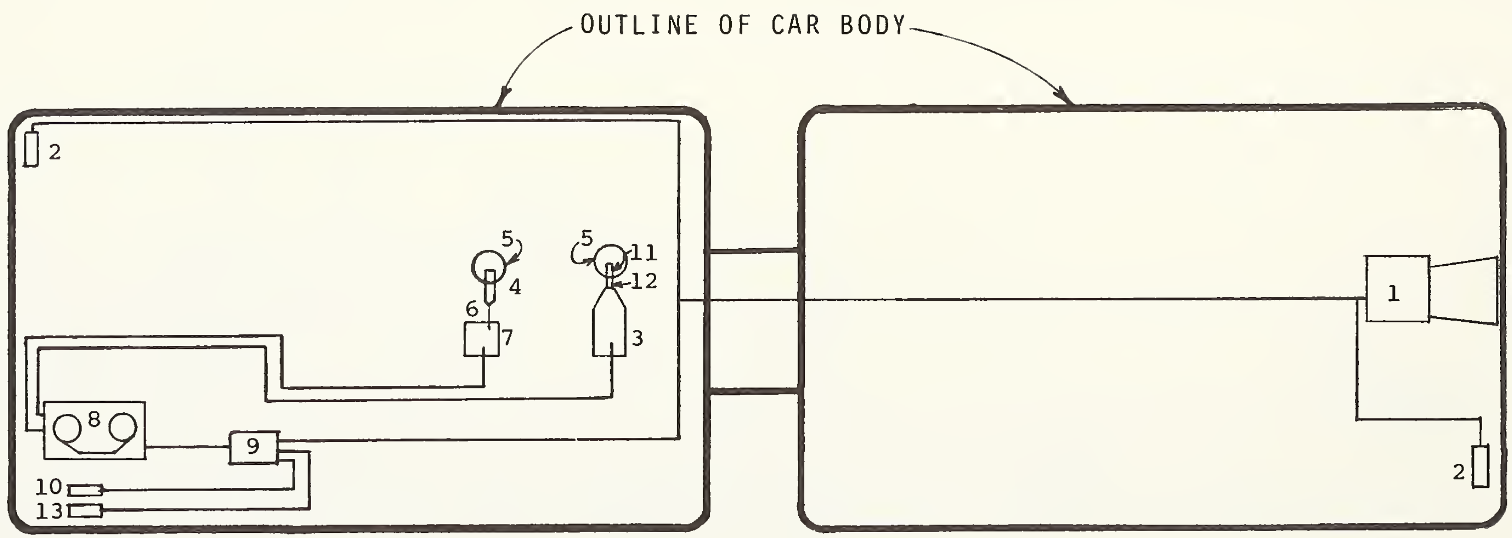


Figure 3-12 Block Diagram of Equipment for Vibration Measurements on Elevated Structure



EQUIPMENT:

1. RADAR SPEEDOMETER
2. REMOTE READOUT PANEL OF SPEEDOMETER
3. B&K SOUND LEVEL METER
4. 1" B&K MICROPHONE & RANDOM INCIDENCE CORRECTOR
5. WINDSCREEN
6. B&K 2619 PREAMPLIFIER
7. WIA POWER SUPPLY FOR B&K 2619
8. NAGRA IV SJ TAPE RECORDER
9. WIA CUE CHANNEL ADAPTOR
10. ANNOUNCE MICROPHONE
11. B&K 4161 MICROPHONE, DESSICATOR UNIT AND RANDOM INCIDENCE CORRECTOR
12. B&K MICROPHONE EXTENSION
13. EVENT MARKER ACTUATOR

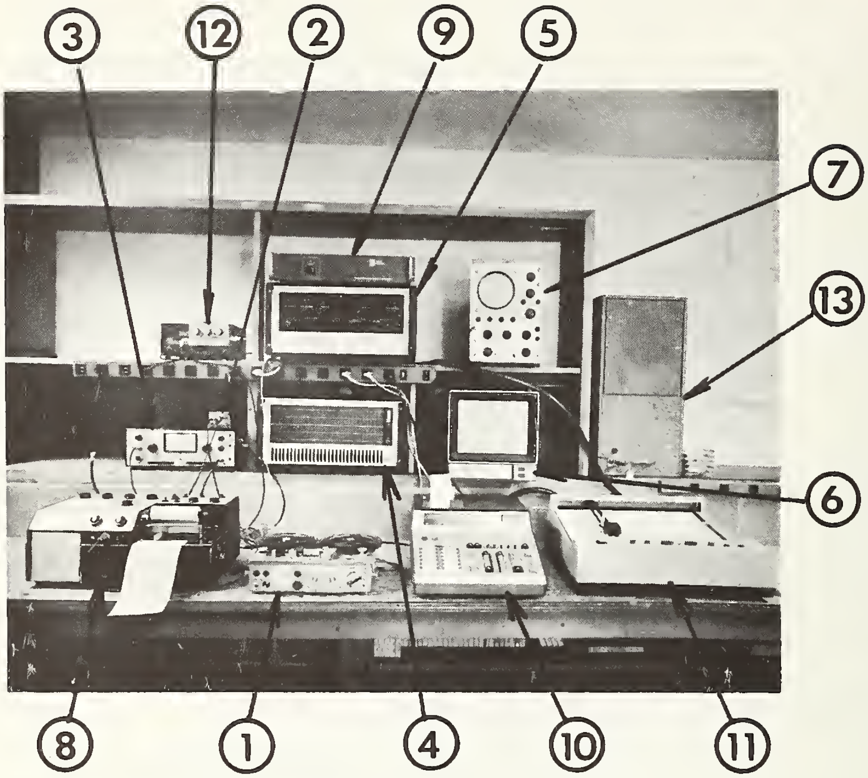
Figure 3-13 Block Diagram of Equipment for Interior Car Measurements

To document the train speed, the output signal from the speedometer will be recorded on the third channel of the tape recorder. Announcements of run number, location, etc., will also be made on the third channel, and a switching box will be provided to activate the announce microphone. Since announcements will not be possible during the actual test run without obscuring the speed information, the tape recorder operator will use an event marker to place an electronic signal on the tape to indicate when a test track is being traversed.

3.4 DATA REDUCTION

The field data collected on magnetic tapes will be returned to the laboratory for reduction and analysis. Figure 3-14 is a photograph of the entire sound and vibration analysis system and Figure 3-15 is a block diagram of the data reduction system for acoustic data.

The amplified signal from the tape recorder is input to the graphic level recorder and the real time analyzer. The trace on the graphic level recorder is used to determine the appropriate location of the noise sample. Typically, a sample length of 2 to 4 seconds will be used for the real time analysis. An event marker on the graphic level recorder indicates the beginning and end of the real time analysis sample. The real time analyzer determines the 1/3 octave band levels, the A-weighted levels and the overall level. The digital results from the real time analyzer are input to the calculator. For each sample the calculator prints out the 1/3 octave band levels, the A-weighted level and the overall level for each sample and stores the results on digital magnetic tape for subsequent retrieval. The calculator is also interfaced with a digital plotter. The



Description and Function of Equipment

1) Nagra SJ 3-channel Magnetic Tape Recorder

- For playing back data tapes

2) Wilson, Ihrig & Assoc. FM Demodulator Type 226

- For demodulating FM recordings of vibration data

3) Bruel & Kjaer Type 2607 Measuring Amplifier

- For amplifying and conditioning playback signals

Figure 3-14 Sound and Vibration Analysis and Data Plotting Equipment

4),5) General Radio Type 1921 Real Time Analyzer

4) G.R. Type 1925 Multifilter

- 1/1 and 1/3 octave filter unit for analyzing frequency content of data signal

5) G.R. Type 1926 Multichannel RMS Detector

- Control unit, detector and analog to digital converter section of real time analyzer

6) Tektronix Type 611 Storage Oscilloscope

- For viewing and monitoring real time analysis results

7) Tektronix 515A Oscilloscope

- For monitoring FM and demodulated signals

8) Bruel & Kjaer Type 2305 Level Recorder

- For monitoring playback signals to determine time for initiating real time analyzer integrations

9) Tektronix Type 152 BCD Interface

- For transfer of data from real time analyzer to programmable calculator

10) Tektronix Type 31 Programmable Calculator with Thermal Printer

- For storage and calculation procedures with data and for printing out real time analysis of data

11) Tektronix Type 4661 Digital Plotter

- For plotting 1/1 and 1/3 octave band charts

12) Altec Power Amplifier

- For amplifying data tape signals for listening during playback

13) Wilson, Ihrig & Associates Monitor Speaker

- For listening to data playback

Figure 3-14 Sound and Vibration Analysis and Data Plotting Equipment (cont'd.)

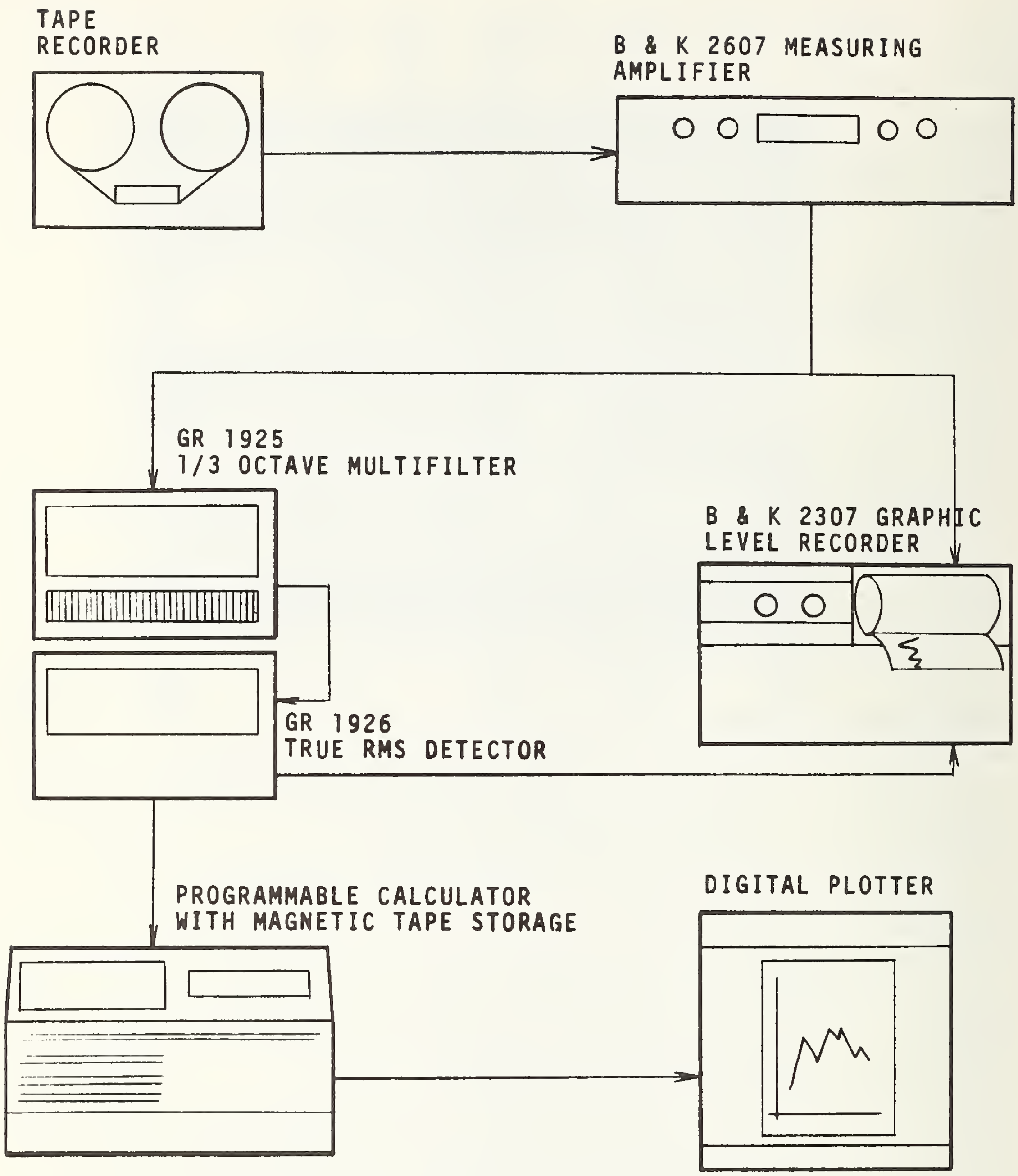


Figure 3-15 Block Diagram of Laboratory Data Reduction System for Acoustical Data

calculator plotter system is programmed to plot the 1/3 octave levels of either individual samples or the average 1/3 octave levels of several samples.

3.5 DATA MANAGEMENT

All numerical values generated in the analysis will be stored digitally on Tektronix magnetic tape cassettes. The data will be available at any time during the study and will be retained after the study is completed in the event that additional data analysis is desired or that the data will be incorporated into future studies.

Nearly 5000 individual samples will be collected in this study. Clearly, with such a large quantity of data, it will be necessary to carefully and accurately catalogue the data. To eliminate confusion of test conditions and to allow easy identification of the data samples stored on the digital magnetic tapes, a classification scheme has been developed. The classification number is an eight digit decimal number that will always be carried with the data sample. It is divided into six parts as indicated below:

a b c d ee ff

This information will be coded in the following format:

<u>a</u> Wheel type: one digit coding

1 - Standard No. 1, pre-worn steel wheels
2 - Standard No. 2, new steel wheels
3 - Resilient No. 1
4 - Resilient No. 2
5 - Resilient No. 3
6 - Damped
7 - Revenue trains
8 - Revenue trains

Two revenue train categories have been included to allow for more than nine revenue train passbys.

b Wheel condition: one digit coding

1 - New
2 - Newly trued
3 - 6 months wear
4 - 12 months wear
5 - 18 months wear
6 - 24 months wear

c Measurement location: one digit coding

1 - Wayside (or on station platform)
2 - Car interior over truck
3 - Car interior at car center

d Run number: one digit

The number of the test run for the specific train in the specific test phase.

ee Track location and direction: two digit coding

01 - Tangent jointed, Test B
02 - Tangent jointed, Test A
03 - Tangent jointed, control
04 - Tangent welded, control
05 - Tangent welded, test
06 - Elevated station
07 - 69th Street turnaround, control
08 - 69th Street turnaround, test
09 - Tangent jointed, subway
10 - Tangent welded, subway
11 - Subway station
12 - Frog, elevated structure

Information on the train direction will be included by adding +20 to the track number when the test track is traversed in the reverse direction.

<u>ff</u> Train speed: two digits

The actual speed of the train during the sample to the nearest kilometer per hour.

As an example, the description number 14262578 would indicate the following:

1	Pre-worn wheels
4	The wheels have approximately 12 months wear
2	The sample is in the car interior over a truck
6	Test run number 6
25	Test track 5 (tangent welded test section) with the train going in the reverse direction
78	The train speed during the sample was 78 kilometers per hour.

3.6 TEST CONTINGENCIES

In a large scale test program such as this study, it is important to plan in advance for possible contingencies or equipment failures that may occur. Some of the equipment failures that would have a severe adverse impact on the collection of the acoustic data are rail failure, wheel failure, development of wheel flats on one set of wheels, and car failure. As much as is possible, each of these possibilities has been anticipated to minimize the impact on the study results. The impact on the study and the measures taken to minimize the impact on the study of each of the contingencies listed above are summarized in the sections below.

3.6.1 Rail Failure

Although rail failure on the test track sections is a relatively unlikely occurrence, even if failure should occur, the impact should not be severe.

Failure of one jointed rail segment should not adversely affect the test measurements. Rails are 39 feet in length and would represent approximately 15 percent of the length of a test section. If a rail section is removed, it is anticipated that it could be replaced with a used rail section with wear similar to that on the test track.

It is possible to have weld failure. However, weld failure is unlikely to cause a problem, especially since on SEPTA rail the weld is commonly protected with a safety strap installed when the rail is welded. Most failures in the rail outside of the weld area, such as rail breaks, would be repaired by installing joint bars in the failure areas. Replacement of a section of welded rail by cutting out the defective length and replacing it with a similar rail would result in two joints being installed in the section of welded rail. If this were to occur, it would be necessary to investigate the influence of the joints on noise radiation with comparative measurements.

3.6.2 Wheel Failure

To protect against the possibility of one wheel failing and being unable to take any further measurements on that type of wheel, extra resilient and damped wheels will be purchased. To have similar wear characteristics on the spare wheels as on the test wheels, the spare wheels will be installed on a transit car used in revenue service.

3.6.3 Wheel Flats

It is possible that due to some emergency or equipment failure that the wheels on a train will be locked and the wheels skidded. The likely result would be the development of wheel flats on a number of the wheels. Clearly, wheel flats will strongly influence the wheel/rail noise. To get useful data, the wheel flats would need to be removed by truing the wheels. This would reduce the amount of data collected with the worn wheels. To estimate the noise radiated with the worn wheels, it will be necessary to extrapolate using the data collected on the other wheel types.

If only one or two wheels on a 2-car train develop wheel flats, it will be possible to true the affected wheels to remove the flats without significantly altering the noise radiating characteristics.

3.6.4 Car Failure

With the exception of the new standard wheels, all wheel sets will be installed on SEPTA cars capable of operating as 1-car trains. Since there are two cars being tested for each wheel type, if one car fails and must be taken out of service, it may still be possible to salvage the study of the specific wheel type with the remaining car. However, if the cars are a married pair, it may be necessary to remove the wheel type from the remaining tests.

In the initial test phase, several measurements will be taken with 1-car trains. These measurements will allow relating measurements with only one car to the 2-car train measurements. Hence, if one car of a 2-car train fails, measurements taken with the remaining car can be used.

3.7 RESTORATIONS

There will be very little restoration to SEPTA facilities and equipment necessary following completion of the testing. The only restoration will consist of replacing the resilient wheels with standard wheels and removing the damping material from the damped wheels.

4. COST DATA AND SURVEY OF OTHER SYSTEMS

Accompanying the development and performance of the testing program, cost data relating to each of the noise control methods will be collected.

The primary source of data on the total cost (initial, operating and maintenance costs) for each of the noise control methods will be observation and analysis of SEPTA operations and costs during the test phase of this study. The costs for labor, materials and equipment associated with each noise control method will be supplemented by provision of professional services and overhead costs where appropriate information can be developed.

Concurrent with SEPTA testing and data collection, a survey of manufacturers, suppliers and other transit systems will be performed. The survey will be primarily concerned with the direct costs which are incurred as an immediate result of the various noise abatement techniques. Indirect costs or savings that arise from secondary impacts made by the abatement program on the transit systems' operations will not be evaluated. For example, purchase of the resilient wheels is a direct cost and will be included, but reduction in the number of cars available for service as a result of the installation program is a secondary impact and will not be included.

Data will be collected from manufacturers and suppliers of the various materials and equipment required to install, maintain, or operate the resilient wheels, the damped wheels, the wheel truing machine, or the rail grinding machines. The survey of other transit systems will develop cost information

and will obtain data concerning any experience other systems have had with the four noise control methods being evaluated. The survey will gather data about systems' operations, the equipment operated, and the physical layout of the system.

In addition, the survey of other systems will investigate the local factors affecting cost on each specific system. However, an attempt will be made to develop one cost for each noise control method that can be validly applied nationally. The cost would be representative but would not be specific to one transit system. The representative unit costs will be calculated using the cost parameter formulae defined in the Experimental Design Report.

The data from the survey will be used to assess the transferability of cost data to other systems as well as the qualitative parameters listed in the Experimental Design Report.

The following transit systems will be contacted:

- New York City Transit Authority (NYCTA)
- Port Authority Trans Hudson Corporation (PATH)
- Port Authority Transportation Company (PATCO)
- Cleveland Transit System (CTS)
- Chicago Transit Authority (CTA)
- Bay Area Rapid Transit (BART)
- Massachusetts Bay Transportation Authority (MBTA)
- Toronto Transit Commission (TTC)
- Washington Metropolitan Area Transit Authority (WMATA)
- Metropolitan Atlanta Regional Transportation Authority (MARTA)

It is not anticipated that data for comparison with the results of this study will be available from the MARTA system, since it is not presently in operation. However, some data will be available from the WMATA Metro system. It will be useful to note, for informational purposes, the methods proposed for noise and vibration control for these two systems, along with the anticipated and available results.

A detailed questionnaire will be submitted to each system, along with an explanation of the objectives of the study. In-depth interviews with engineering, car equipment, and noise control personnel will be conducted. Coordination with the testing program will assure that appropriate data is developed so that, upon completion of the test program, the acoustical effectiveness and life expectancy may be balanced against the costs and problems associated with equipment of the four noise control techniques.

Below is an outline summary of the specific information to be gathered from each system:

1) Resilient wheel and damped wheel experience

   a) Resilient wheels - Acousta Flex, Penn Bochum, SAB, or damped wheels investigated or installed

      1) In test program or regular service

      2) Type investigated

      3) Number installed

      4) Time tested or in service

      5) Maintenance requirements - inspection, truing

      6) Observed problems

      7) Results, conclusions regarding noise reduction

        8) System or operating characteristics that would restrict installation of resilient damped wheels on the system

    b) Planned future test programs

2) Rail Grinding Experience

    a) System's ongoing rail grinding program. Plans for developing or expanding program.

    b) Equipment used

        1) Speno: owned, leased or rented. Number used.

        2) Abrasive bricks

    c) Basis for establishing program

        1) Method of establishing priorities

        2) Program cycle

        3) Physical measurement of rail corrugation or roughness

        4) Is noise reduction reason for grinding?

    d) Costs associated with grinding

        1) Manpower

        2) Equipment

        3) Support labor

    e) Rail wear characteritiscs

        1) System characteristic or car operating conditions affecting growth of corrugations

        2) Areas of highest incidence of corrugation

3) Conditions or characteristics limiting use of grinders

f) Observed or measured effectiveness of rail grinding on noise reduction

1) Has relative growth of corrugations been estimated?

3) Wheel Truing

a) System's ongoing wheel truing program

b) Equipment utilized

1) Underfloor - lathe, milling

2) Above floor

3) Other - hand grinders, etc.

c) Program scheduling

1) Cycling of cars. Are cars programmed cyclically? Average car miles between truing. Maximum allowable wear before truing. Criteria for condemnation.

2) Incidence of flat spots. Observed causes.

3) Number of truings normally performed per wheel during normal life cycle

d) Existing capacity

1) Cars trued per day per location

2) Factors limiting capacity

e) Expected wheel life in miles

f) Truing costs

1) Manpower

2) Equipment

g) System characteristics or car operation conditions most affecting dominant wheel wear pattern

h) Occurrence of wheel wear problems

1) Thermal cracks

2) Spalling

3) Shelling

i) Observed or measured effectiveness of wheel truing on wheel wear and noise

4) Car Data

a) Number of cars owned or operated

b) Wheel diameter

c) Braking systems

d) Average annual car miles

e) Inspection schedules

APPENDIX

REPORT OF INVENTIONS

A detailed review of work performed under this contract to develop the material indicated in this report has not disclosed any discoveries or inventions at this time. However, a major innovation resulting from contract work to date is the development of a detailed test and evaluation plan to produce definitive engineering data on the long term costs and performance of four noise abatement techniques for which such data are presently lacking. The four noise control methods are the use of; resilient wheels on transit cars, vibration damping treatment on standard transit wheels, wheel truing, and rail grinding. This entire report describes the test and evaluation plan.

One requirement of the test plan is to monitor the accumulated mileage of the test cars. Since the SEPTA cars are not equipped with odometers, monitoring the mileage has been accomplished through the use of hub mounted odometers. An innovation developed under this contract is the vibration isolation mounting of the odometers to the hub of the transit car wheels. Figure A-1 is a simplified cross-section view of the vibration isolation system designed to mount Engler Revo-Count odometers to the hubs of the SEPTA wheels and a photograph of an installed Revo-Count.

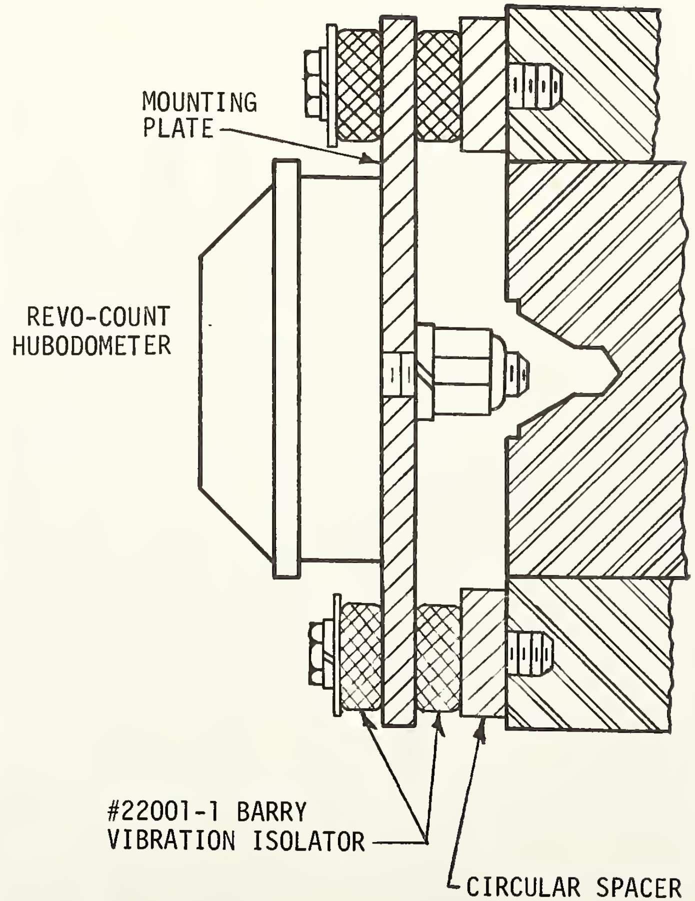


Figure A-1 Vibration Isolation Mounting of Rev-Count Hubodometer